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# First Break of the Seismic Signals Based on Information Theory

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***Abstract***

For the seismic data with low SNRs, the first arrival automatic picking method is very important but difficult. In the paper, we proposed a new method based on the mutual information in information theory. The mutual information between signals and noises is zeros, thus random noises have less effects on first arrivals pickup. The paper compares the principle of STA/LTA, AIC, fractal dimension of three kinds with the proposed method for seismic data first–break picking method, and at the same times, the paper presents a detailed test and verification of the simulation data, and compares first–break picking accuracy and efficiency of the three algorithms through actual data with different S/N ratios. The results show that for the data with high S/N ratio, first break picking accuracy of these four methods is relatively high. When SNR decreases, first–arrival time that the proposed method picks has higher precision and good noise immunity. However, mutual information based method has lower efficiency and is limited by algorithm principle. it is difficult to separately pick first breaks for fractal dimension and AIC method. So it is a very good method to identify seismic events and determine preliminarily the time range of first breaks by the proposed method.

***Keywords***

*Seismic Data; First Arrivals; Pickup; Information Theory; Mutual Information*

## Introduction

In seismic exploration, first-break picking is the task of determining, given a set of seismic traces, the on sets of the first signal arrivals as accurately as possible. In general, these arrivals are associated with the energy of refracted waves at the base of the weathering layer or to the direct wave that travels directly from the source to the receiver [5].

The accurate determination of the first arrivals onset first-break times is needed for calculating the static corrections, a fundamental stage of seismic data processing. Clearly, the effectiveness of reflection and refraction-based methods of static corrections depends on the picking-process reliability. At the same times, applications such as near-surface tomographic static corrections tomographic statics require rapid automated detection of the signal first.

Generally, first-break quality is related to the near-surface structure, source type, and signal-to-noise ratio S/N conditions. As a consequence, the automated picking of first breaks can be a very difficult task if data area acquired in complex near-surfaces scenarios or if the S/N is low. Moreover, if the source wavelet is zero-phase as when vibroseis sources are used, the sweep correlation often produces side-lobes that arrive before the first break, thus making the picking process even more difficult.

First arrival pickup of seismic waves, so far, has had a lot of methods. According to the criterion, first-arrival picking algorithms can be divided into several types of methods, including the coherence method [3, 4] cross-correlation method [2], neural network method [1] and fractal dimension methods [7]. For the coherence and neural network methods, some kinds of patterns are assumed for picking the first arrivals. Therefore, pattern recognition of this type is effective if a simple earth model exists to model the earth structure. However, this simple earth-model rarely matches the near-surface conditions when studied with the detail required of most modern surveys [6]. The advantages of the cross-correlation methods are that the algorithm is based on trace-by-trace evaluation of the first-arrival times and are considered to be most appropriate for the near-surface surveys.

In the paper, we proposed a robust method of first-break picking for data sets with high noise levels through

theuse of the information theory on seismic records. Using synthetic shot records with various noise levels, we showed that the performance of this proposed method enhances first arrivals, which helps in picking them. This was particularly true when the noise level was high where picking on raw amplitudes completely fails. The method can be used to guide better the subsequent careful picking of first arrivals and requires one forward. In contrast to methods based on trace-by-trace picking that often fail to pick some traces, the proposed method automatically interpolates missing picks.

## Basics of Information Theory

The average amount of information gained from a given discrete space $X$ is the entropy $Y$,

$$H(X) = -\sum_i P(x_i)\log P(x_i) \quad (1)$$

If the log is taken to the base two, $H$ is in units of bits. Entropy of information in information theory can be defined as follows. For given discrete probability space, which expressed information source and the information source defined random variable $I$. The mathematical expectation of $I$ is entropy of information of information source, whose unit is bit/symbol.

$$H(X) = E[I(x)] = -\sum_i p(x_i)\log p(x_i) \quad (2)$$

The conventional mutual information has been defined as:

$$I(X,Y) =_{X,Y} f_{XY}(x,y)\ln\frac{f_{XY}(x,y)}{f_X(x)\, f_Y(y)}dxdy \quad (3)$$

where, $f_{XY}(x,y)$ is the joint probability density function (PDF), and $f_X(x)$ and $f_Y(y)$ are the marginal PDFs of variables $X$ and $Y$, respectively.

Mutual information can also be equivalently expressed as:

$$\begin{aligned} I(X;Y) &= H(Y) - H(Y/X) \\ I(X;Y) &= H(X) + H(Y) - H(XY) \end{aligned} \quad (4)$$

Actually, the mutual information is very difficult to calculate since the probabilities of variables $X$ and $Y$ are quite difficult to get. In the paper, we propose a new method to calculate the mutual information based on the recursive idea. In principle, the mutual information is a kind of measuring how dependent the variable of $X$ are on the variable of $Y$.

By making the assignment, $[s,q] = [x(t), x(t+T)]$, we can consider a general system $(S,Q)$, then the uncertainty of measurement of $q$, given $(S,Q)$, is

$$H(Q \mid s_i) = -\sum_j P_{q|s}(q_j \mid s_i)\log P_{q|s}(q_j \mid s_i) \quad (5)$$

where $P_{q|s}(q_j \mid s_i)$ is the probability that a measurement of $q$ will yield $q_j$, given that the measured value of $s$, is $s_i$. At the same time, the average uncertainty in a measurement of $x$ at the time $t+T$ can be shown given that $x$ has been measured at time $t$,

$$H(Q \mid S) = \sum_i P_s(s_i) H(Q \mid s_i) = H(S,Q) - H(S) \quad (6)$$

where,

$$H(S,Q) = -\sum_{i,j} P_{q,s}(q_j, s_i)\log P_{q,s}(q_j, s_i) \quad (7)$$

$H(Q)$ is the uncertainty of $q$, and $H(Q \mid S)$ is the uncertainty of $q$ given a measurement of $s$. So the amount that

a measurement of $s$ reduces the uncertainty of $q$ is according to the equation (4)

$$I(Q,S) = H(Q) - H(Q \mid S) \quad (8)$$

It is important that mutual information is not a function of the variables $s$ and $q$, but that it is a functional of the joint probability distribution $P_{sq}$. If $s$ and $q$ are the same to within the noise, then $(S,Q)$ specifies the relative accuracy of the measurements in bits, i.e., how much information one measurement gives about a second measurement of the same variable.

If $S$ is a delayed image of $Q$, then a delay phase portrait gives the estimated joint distribution $P_{sq}$ and $I$ is a statistic calculated on the portrait that evaluates how redundant the second axis is.

## New Method for First Arrivals

The calculation method of mutual information of the arbitrary $A$ and $B$ two channels on seismic record is performed with the software "Smart Signal Processing" developed by Prof. Ming-Yue ZHAI at North China Electric Power University, and steps are as follows:

(1): Firstly, we should intercept the seismic wave whose length is $L$ on $A$ channel, taken down: $\{x(n)\}_{n=0,1,...L-1}$, $L$ is the length of sequences. Then the range of sequence $x$ is divided into equal parts which $M$ is interval, at last we count the sampling point that falls into the every interval and calculate the probability distribution $p(x)$ of sequence $\{x(n)\}_{n=0,1,...L-1}$.

(2): Secondly, $\{x(n)\}_{n=0,1,...L-1}$ whose length is $L$ slides on channel $B$ with a certain step. The mutual information is taken down when it slides one time, and this mutual information is the one of the $\{x(n)\}_{n=0,1,...L-1}$ and $\{y(n+d)\}_{n=0,1,...L-1}$. For the channel $B$, we will fill the insufficient parts with random sequences, and then we can get the mutual information $I(d)$.

(3): For, $I(d)$, $d = 0,1,...$. The maximal $(d)$ is $I(D_{\max})$. Now, we think this is the first arrival time. The value of L is more than $100$. The value of M is about $16$ to $64$.

In the foresaid algorithm, the seismic mutual information of channel $A$ and channel $B$ need to be calculated. Because calculation is very complicated, the paper improves the algorithm in order to reduce the amount of calculation.

Through the calculation of mutual information, we get the maximal value of the mutual information. The time that it corresponds is first arrival time of seismic waves. This method is more accurate than the ratio of energy method. However, it needs to calculate mutual information from the first channel to the last channel, whose amount of calculation is very huge. But the advantage is that mutual information is accurate and robust, because random noises are uncorrelated with signals of interesting and thus the mutual information is zero for such case.

We can explain it as a measure of the amount of information one random variable contains about another random variable, thus it is the reduction in the uncertainty of one random variable due to the knowledge of the other. Mutual information is not an invariant measure between random variables because it contains the marginal entropies. Normalized Mutual Information is a better measure of the “prediction” that one variable can do about the other

## Applications to Simulated Signals

In the section, we applied the proposed method to a seismic profile, which is generated by the time-delayed line models (TDL). The wavelet used in TDL model is Ricker wavelet, with center frequency $10\ Hz$. The simulated data without noise is illustrated in Fig. 1, and the noisy version of the simulated data is plotted in Fig. 2. As an example, Fig. 3 illustrated the results of the proposed method. From the simulations, we can see that the proposed method can obtain the precise first arrivals even under very low SNR.

From above-mentioned figures we can know that, when SNR is very high, the proposed methods can pick up the first arrival very well. With the reduction of SNR, error of ratio of energy method changes larger, and a lot of bad points appearance. We cannot accurately pick up the first arrival. When SNR is $5dB$, the method based on the mutual information can calculate the mutual information from the first channel to the end channel. At the same times, it only calculates a part of mutual information. For calculating the part of mutual information, amount of calculation of mutual information are the same. To evaluate the performances of the proposed method under different SNRs, we applied it to the simulated data with different SNRs. The results are illustrated in Fig. 4. From such figure, we can see that the errors are very low.

## Conclusions

First arrivals pickup is a very important issue in seismic data processing. In the paper, we proposed a new method with the help of the mutual information. In such method, there is no any assumption for the data. Therefore, the proposed method can be applied to any seismic data. Especially, the mentioned method can work very well under very low SNRs environments, because the mutual information between data and noise is zero, and thus noises can affect arrivals pickup as less as possible.

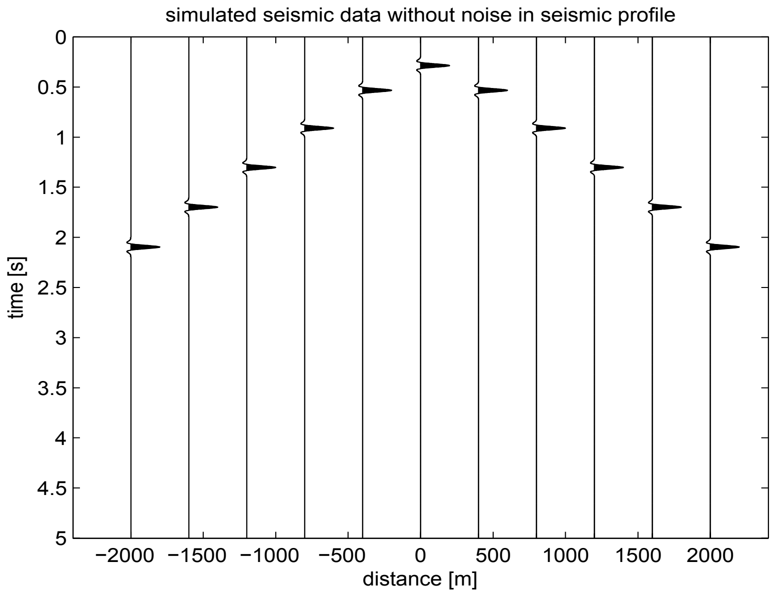


FIGURE 1. THE SIMULATED SEISMIC PROFILE WITH TDL MODEL WITHOUT NOISE

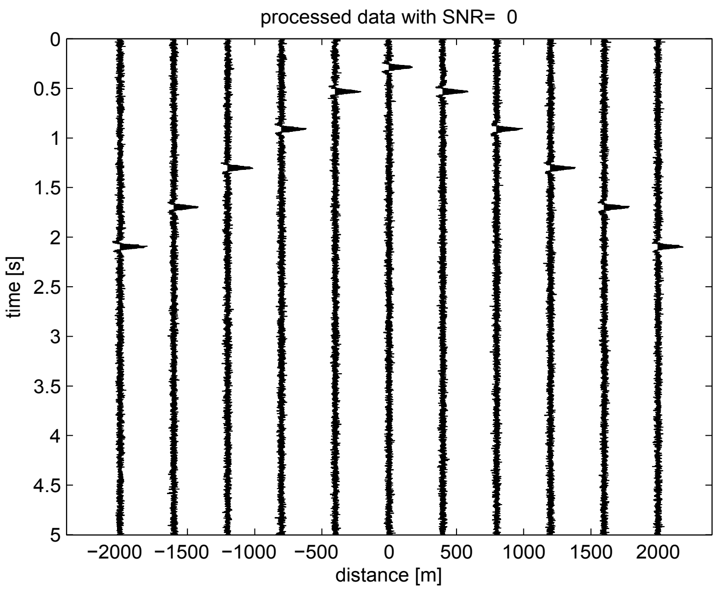


FIGURE 2. THE SIMULATED SEISMIC PROFILE WITH NOISE

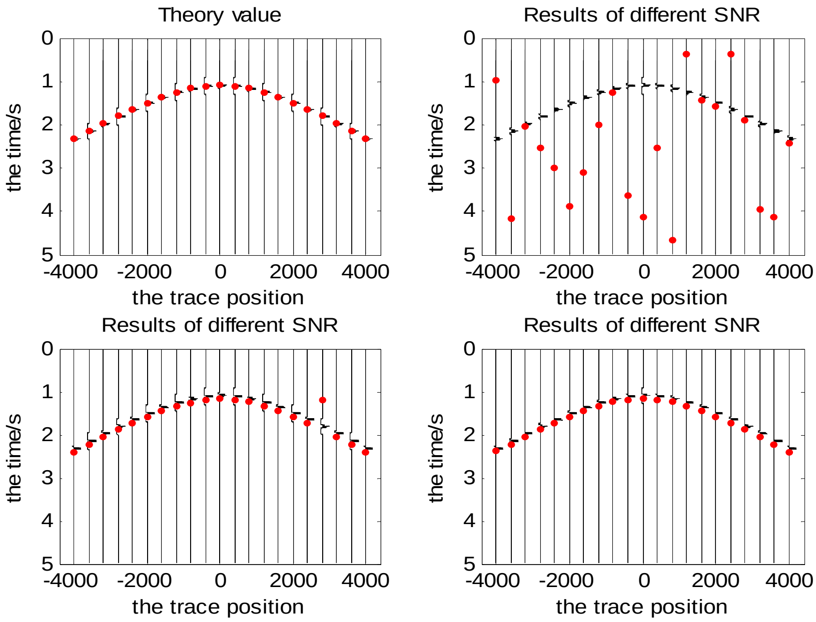


FIGURE 3. AN EXAMPLE OF FIRST ARRIVAL PICKUP WITH THE PROPOSED METHOD

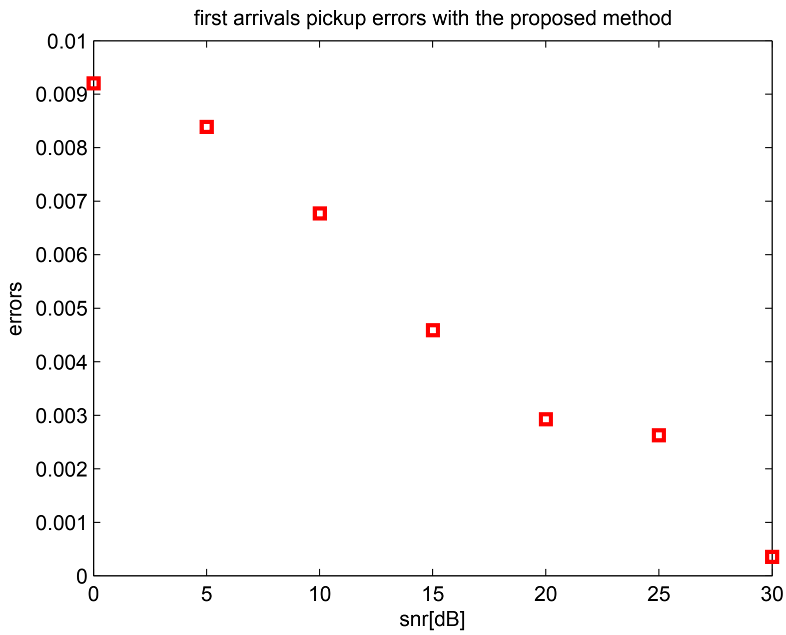


FIGURE 4. ERRORS FOR THE FIRST ARRIVAL PICKUP WITH THE PROPOSED METHOD

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